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MOTIVE: FUNCTIONAL SPECIFICATIONS FOR MOMENT TENSOR INVERSION

VELA SEISMOLOGICAL CENTER

G.R. Mellman, R. Strelitz, G.M. Lundquist, and R.S. Hart
Sierra Geophysics, Inc.
15446 Bell-Red Road
Redmond, Washington 98052

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This document contains the functional specifications for a program to invert for source properties using a moment tensor source description. The program structure is discussed; individual subroutines are named and their function is specified, and common blocks are named and their variables identified. Though not a final working program, these functional specifications determine the orientation, flow and interaction of the software in detail which will be exceeded only by the code itself.

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INTRODUCTION

A number of techniques are currently available for seismic discrimination and yield estimation. Most of these methods, however fail to fully utilize the available azimuthal information and, indeed, many methods for magnitude estimate use only a single amplitude measure. Shallow earthquakes will, in general, produce waveforms and amplitude patterns that vary azimuthally while a pure explosion in theory produces azimuthally independent waveforms and amplitudes. This fact is not utilized in most discrimination schemes. In the yield estimation context, azimuthal variations in waveform and amplitude may contain information on tectonic release for which a correction should be, but is usually not, made in obtaining yield estimates. In this document, we describe a computer program, MOTIVE, which makes use of this azimuthal information, as well as utilizing significant portions of the waveform information, in both discrimination and yield estimation contexts.

MOTIVE is a joint body wave and surface wave moment tensor inversion program. Given properly windowed body wave and surface wave seismograms and a trial depth, MOTIVE determines the second order moment tensor that provides the best fit, in a least squares sense, of synthetics to the data. By using a number of trial depths and selecting the depth that produces the minimum error, depth, as well as source type and orientation, may be determined.

MOTIVE incorporates several unique features in addition to the joint use of body wave and surface wave data. The user can specify any of four source types; an unconstrained moment tensor, an isotropic source, a double couple source and a double couple plus isotropic source. This gives the user the ability to explore the sensitivity of his solution to the most commonly made physical assumptions about the source. Moreover, MOTIVE can include state-of-the-art body wave and surface wave path and receiver corrections, determined for each source-station pair. This should help eliminate one of the major sources of error and bias in moment tensor estimation, particularly where short-period body wave seismograms are used.

A flexible modular approach has been used in developing MOTIVE, in order that the same program, through choice of user options, may be used for both routine processing and research. This flexibility also insures that future improvements can be readily incorporated into the existing program structure.

ABSTRACT

This document contains the functional specifications for a program to invert for source properties using a moment tensor source description. The program structure is discussed; individual subroutines are named and their function is specified, and common blocks are named and their variables identified. Though not a final working program, these functional specifications determine the orientation, flow and interaction of the software in detail which will be exceeded only by the code itself.

PROGRAM STRUCTURE

The moment tensor package MOTIVE may be conveniently divided into several functional modules, each containing several subroutines. Communication between modules is through common blocks and data files. By maintaining the functional independence of these modules, it becomes a relatively simple matter to incorporate major modifications in the overall system, both in a research mode or, if warranted by future research, in a production mode. In addition, it becomes possible to maintain several options for any functional portion of the program, where option choice is specified by a user set flag. This would allow the user to assess the effect, for instance, of a different choice of error function, and hence different partial derivatives, on the final solution, without a major restructuring of the program.

A flow diagram illustrating all major program modules is shown in Figure 1. The first module encountered is the input module. This module consists of a single subroutine which reads station independent parameters, such as source model, the number of body and surface wave stations to be employed, which program options are to be used, and trial source depths.

The body wave and surface wave modules each have two basic functions. These are the input and preprocessing of the appropriate data type for each station and the generation of primitive Green's functions and partial derivatives for each moment tensor element and station. As the body and surface wave inversions employ different types of data, the two modules must have somewhat differing structures, although parallel construction has been used where possible.

The data used by the surface wave portion of the inverse are complex amplitudes at several frequencies. Thus, the surface wave program must obtain a seismogram from a data files and perform a Fourier transform (or narrow band filter) to obtain a spectral estimate. From the source to station distance and azimuth, Green's functions at the appropriate frequencies are then computed, using table lookup for a standard model. These Green's functions are then corrected for the specific path, where such information is available. These corrections, which include attenuation, dispersion, multipathing and site amplification effects, are to be provided by Systems, Science and Software, Inc. in the form of a table containing corrections for each source region-station pair. Data and Green's function spectral amplitudes are then packed into data and partial derivative arrays, respectively, for use by the inversion module.

Data used by the body wave portion of the inverse are in the form of time series. Thus, for each station, data

PROGRAM MOTIVE

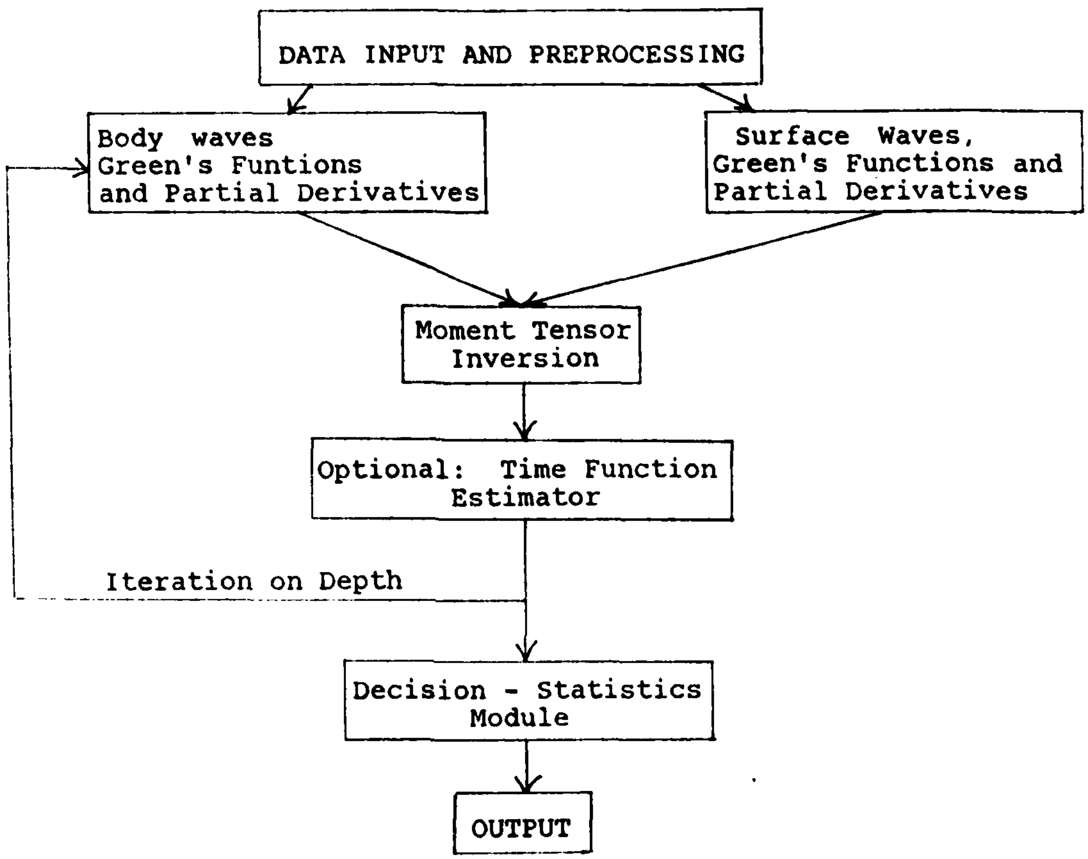


Figure 1. Flow diagram for program MOTIVE

must be obtained from a data file, aligned in time, prefiltered, windowed and normalized. Green's functions are computed in two stages, corresponding to depth independent and depth dependent portions. The depth independent portion consists of geometric spreading, residual attenuation, receiver function, instrument and assumed source time function. Of these, geometric spreading and attenuation are obtained by table lookup and subroutine calculation, respectively, while instrument and receiver functions are obtained from pre-existing files. These files are accessed using information provided on input for each station.

The depth dependent portion of the Green's functions are computed in a Haskell matrix program for each moment ensor. These depth dependent portions are then convolved with the depth independent preliminary Green functions. The resulting Green's functions are time aligned, normalized, filtered and windowed in precisely the same way as were the data for that station. Data and Green's fnctions are then packed into data and partal derivative matrices, respectively, for use by the inversion module.

The inversion module uses the partial derivative and data arrays constructed in the body and surface wave modules to construct a moment tensor that minimize the difference between model and data in a weighted least squares sense. Non-linear constraints are iteratively applied to a linear, stabilized least squares inversion, so that optimal isotropic, double couple, isotropic plus double couple, or unconstrained moment tensor solutions are available to the user.

Following the inversion module is an optional time function estimation module, which will be discussed below. The optimal moment tensor solution for that depth, together with the Green's function partial derivative arrays and the error function for that depth are passed to the decision and statistics module. Here the source depth, moment tensor and total error are stored. If the total error is a minimum compared to tht determined for other depths, the Green's functions and partial derivatives are also stored. The program then loops back to the body wave module in order to process the next trial source depth.

When the iterations over source depth are completed, the decision module outputs a table of depths, moment tensor solutions and total errors. For the depths at which minimum error occurs, a variance and data importance matrix are also produced. For comparison purposes, at the option of the user, plots of the solution time function may be obtained, if this option has been implemented, as well as plots of data and synthetic seismograms.

CALLING SEQUENCE

```
MOTIVE
     FLAP
          MODIN
     SENSE
          SURFIN
               SEISIN
               UPNORM
               COOLB
               GBANDP
               PAW
          SEGRIN
               SWCSSS
               UPNORM
               GBANDP
               PAW
     PENSE
          RAYPRM
          PODIN
               SEISIN
               SMOOTH
               UPNORM
               PAW
          PGRIN
               Q2
               GEOM
               RRFRD
               RDINST
     HACK
          REMOD
          WRATH
               HASK2
               SMPHS
               INTRP
     GRAFT
          COOLB
          SMOOTH
          TSHFT
          UPNORM
          PAW
     MOTEST
          ASETUP
          MATACM
               PACK2
               WT2
          VECMAT
          MATINV
               MINV
          LSOLVE
          MSPLIT
               EIGEN
               PACK
               VC2ANG
```

```
          YPERTB
               WT2
          SRSTEST
          DATACM
          CNSTR
          CONCOR
               MATINV
               MAPROD
          VARNC
               HEXT
     DECIDE
          OUTPUT
```

Program MOTIVE

This is the main program controlling input of data, computation of Green's functions, inversion for moment tensor components and output of results. The program is executed by seven modules, three of which are basically input, three of which are executed in a loop on depth, and the last one of which is a summary and output module.

CALLS:

(1) FLAP - Reads station independent flags and parameters. Surface wave input and set-up. Reads and preprocesses surface wave data. Defines surface wave Green's functions. Makes both available to moment tnesor inversion module.

(2) SENSE Surface wave input and set-up. Reads and preprocesses surface wave data. Defines surface wave Green's functions. Makes both available to moment tensor inversion moduel.

(3) PENSE - P-wave input and set-up. Reads and preprocesses observed P-wave seismograms and packs data into data vector with surface waves. Computes preliminary P-wave Green's functions lacking only the source crustal interaction which must be done in loop on depth.

(4) HACK - Thompson-Haskell matrix package to compute source crustal response as a function of source depth and moment tensor component.

(5) GRAFT - Computes final P-wave Green's functions for each moment tensor component for the current depth and packs in same Green's function vector with surface wave Green's functions.

(6) MOTEST-	Moment tensor estimation Performs the moment tensor inversion to final best isotropic source, best double couple source or best isotropic plus double couple source, as requested, for the current depth.
(7) DECIDE-	Decision and statistics module. Compares results of moment tensor inversion at the depths tested; determines overall best fit and computes supporting statistics. Does graphic and tabular output of final results.

Input: MOTIVE does no direct input

Output: MOTIVE does no direct output

Subroutine FLAP

Does flag and parameter input, and inputs the source crustal model. Flags input here are station independent.

Called by:	MOTIVE		
Calls:	MODIN	-	reads crustal model file.
Input:	none		
Reads:	NSTAS, NSTAP	-	numbers of stations for input of surface wave and P-wave data, respectively
	DTS, DTP	-	sample intervals
	NPS, NPP	-	desired data lengths
	TSMS, TSMP	-	smoothing lengths
	HMIN	-	minimum source depth
	DH	-	increment of source depth
	NH	-	number of source depths
	NITER	-	number of interations in moment tensor inversion module
	ITYPE	-	determines source type in the moment tensor inversion
	option flags	-	currently undefined

Output flags are made available to other routines through common blocks.

Subroutine MODIN

Routine reads name of diskfile containing source crustal model, opens file, reads data, and closes file. Model data are made available to Haskell matrix routine in COMMON/MOD/.

Called by	:	FLAP		
Calls	:	none		
Input	:	none		
Reads	:	NLAY	-	number of layers in crustal model
		ALPHA	-	layer P-wave velocity
		BETA	-	layer S-wave velocity
		DENS	-	layer density
		THICK	-	Layer thickness

Output: Read values are made available to other routines in COMMON/MOD/.

Subroutine SENSE

This is the major calling subroutine for entry of observed surface wave data and generation of corresponding Green's functions.

Called by :	MOTIVE		
Calls :	SURFIN	-	Inputs, manipulates and stores observed surface wave data in parameteric form
	SGRIN	-	Generates surface wave Green's functions and stores parametric representation corresponding to observed data.
Input :	NSTAS (in/FLAGS/)	-	number of stations with surface wave data
Reads :	STID	-	4 column station indentifier
	DEL	-	epicentral distance in degrees
	AZ	-	azimuth
	QEFF	-	effective Q (optional)
	WT	-	estimate of station or record quality
Output :	None		

Subroutine SURFIN (KS)

This is the calling subroutine for entry and manipulation of observed surface wave data. Input data is parameterized by its complex amplitude at selected frequencies before storage in a data vector.

Called by	:	SENSE		
Calls	:	SEISIN	-	reads seismogram from diskfile
		UPNORM	-	normalizes seismogram to unit power
		COOLB	-	utility Fast Fourier Transform routine
		GBANDP	-	Gaussian bandpass filter
		PAW	-	Puts parameterized seismogram into data vector
Input	:	KS	-	station number
Output	:	FNORM	-	normalizing factor for current seismogram
		DV	-	data vector output through PAW

Subroutine SEISIN (SEIS, NPP)

This routine reads window flags, file name, opens disk file, reads seismogram, closes disk file and puts seismogram in proper form for later manipulations.

Called by: SURFIN, SGRIN, PODIN, GRAFT

Calls:
- OPENIN - open a disk file for input
- RDDSK - system routine for direct disk I/O
- CLOSE - closes diskfile
- INTERP - linear interpolator

Input: NPP - desired number of points for P-wave seismogram

Output: SEIS - seismogram

Subroutine UPNORM (X, NP, SNORM)

Determines total power in array X and normalizes array X to unit power. If SNORM is negative upon entry, then the routine does not compute power but uses the absolute value of SNORM as the normalizing factor.

Called by: SURFIN, SGRIN, PODIN, GRAFT

Calls: None

Input:
X - array to be normalized
NP - length of X
SNORM - power in array X upon input

Output: X - normalized to unit power

Subroutine COOLB (NN, XX, SIGNI)

Utility subroutine for computation of Fast Fourier Transforms.

Called by: Various

Calls: None

Input:
XX - complex array to be transformed
NN - power of 2 describing length of XX
SIGNI - Forward transform done when SIGNI = -1.0; inverse transform done when SIGNI = 1.0.

Output: XX - transformed version

Subroutine GBANDP (X, IF1, IF2, IF3, IF4,)

Routine to perform a Gaussian bandpass operation on the spectrum of X.

Called by	:	SURFIN, SGRIN		
Calls	:	None		
Input	:	X	-	Complex frequency domain array
	:	IF1-IF4	-	frequency designations for limits of the passband
Output	:	X	-	filtered version

Subroutine PAW (X, NP, IDG)

This routine is a versatile packing program which inserts data of (potentially) variable lengths into a single vector. The vector type is data vector (IDG.LE.0) or Green's function vector (IDG.GT.0).

Called by: SURFIN, SGRIN, PODIN, GRAFT

Calls: None

Input:
- X - array to be packed
- NP - length of X
- IDG - flag determining into which vector X will be packed.

Output:
- ISTA, JSTA - counter of how many X arrays have been packed in vectors
- ICOUNT, JCOUNT - counter of how many points have been packed in vectors
- DV - data vector of length ICOUNT containing ISTA seismograms
- GV - Green's function vector of length JCOUNT containing JSTA Green's functions

Subroutine SGRIN (KS)

This is the calling routine for calculating surface wave Green's functions. The Green's function may be visualized as the impulse response of the total travel path from source to receiver, including instrument. The surface wave path corrections will be provided by Systems, Science and Software, Inc. The Green's functions are parameterized in the same way as the data and are stored in a Green's function vector.

Called by	:	SENSE		
Calls	:	SWCSSS	-	Reads surface wave path correction
		RDINST	-	Reads instrument response and returns filter for convolution
		UPNORM	-	Normalizes Green's function with same factor as used in data
		COOLB	-	Utility Fast Fourier Transform routine
		GBANDP	-	Gaussian bandpass filter
		PAW	-	Packs parameterized Green's function for each moment tensor component into Green's function vector
Input	:	KS	-	station number
Output	:	GV	-	Green's function vector output via PAW

Subroutine SWCSSS (KS)

Routine reads surface wave path correction function via table look-up from data provided by Systems, Science and Software, Inc. The path correction depends function should include attenuation, dispersion, multipathing and site amplification effects and should be supplied for each source region-station pair.

Called by	:	SGRIN	
Calls	:	undetermined	
Input	:	KS -	station number
Output	:	SWGF -	surface wave Green's function in the frequency domain

Subroutine PENSE

This is the major calling subroutine for entry of observed P-wave data and generation of P-wave Green's functions.

Called by:	MOTIVE		
Calls:	PODIN	-	Inputs, manipulates and stores observed P wave data
	PGRIN	-	generates preliminary P wave Green's functions for later convolution with Haskell matrix response.

Input: NSTAP (in/FLAGS/) - number of stations with P-wave data

Reads:	STID	-	4 column station indentifier
	DEL	-	epicentral distance in degrees
	AZ	-	azimuth
	TSTAR	-	travel time/effective Q
	TAU2	-	absorption band parameter
	WT	-	estimate of station or record quality

Output: Variables read in are passed in COMMON/STA/

Subroutine RAYPRM (DEL, P)

Computes ray parameter using distance and a table look-up based upon the Jeffries - Bullen travel time tables.

Called by : PENSE

Calls : none

Input : DEL - epicentral distance in degrees

Output : P - ray parameter in COMMON/STA/

Subroutine PODIN (KS)

This is the calling subroutine for entry and manipulation of observed P-wave data and for packing of that data into a data vector for use in the inversion module.

Called by:	SURFIN PENSE		
Calls:	SEISIN	-	reads seismogram from diskfile
	SMOOTH	-	performs a running average smoothing of the seismogram. (May be replaced by a bandpass filter operation.)
	UPNORM	-	normalizes seismogram to unit power
	PACK	-	packs seismogram in data vector
Input:	KS	-	station number
Output:	FNORM	-	normalizing factor for current seismogram. Will be used to normalize Green's function.

Subroutine SMOOTH (X, NP, DT, TSM)

Performs a running average smoothing of array X. The number of points in the running average operator is defined by TSM/DT.

Called by: PODIN, GRAFT

Calls: None

Input:
- X - array to be smoothed
- NP - number of points in X
- DT - sample interval for X
- TSM - time width of smoothing operator in seconds

Output: X - smoothed version

Subroutine PGRIN (KS)

This is the calling subroutine for the calculation of preliminary Green's functions for P waves. The Green's function may be visualized as the impulse response of the total travel path from source to receiver, including instrument. This routine calculates the response of all parts of the path except the source crustal response which must be done in an iteration on source depth.

Called by: PENSE

Calls:
- Q2 - computes the anelastic attenuation
- GEOM - computes geometric attenuation
- RDRRF - reads relative receiver function and prepares for convolution
- RDINST - reads instrument response and prepares for convolution

Input:
- KS - station number

Output:
- PWC - P-wave Green's function. Actually a preliminary or primitive Green's function in that neither the source nor the source crustal response are included. (output in COMMON/PGREEN/)

Subroutine Q2 (DT, TSTAR, TAU2, QF)

Generates the analytic transform of a frequency dependent Q filter as defined by Minster (Geophys J. R. Astr. Soc., 52, P. 503, 1978).

Called by: PGRIN

Calls: None

Input: DT - sample interval in time domain
TSTAR - travel time/affective Q
TAU2 - absorption band parameter. To get frequency independent Q, set TAU2= .001

Output: QF - the desired Q filter in the frequency domain.

Subroutine GEOM (DEL, GSPRD)

Computes geometric spreading factor based upon surface-to-surface travel path. This gain factor is based upon a parameterization of a curve defined by Langston (Ph.D. thesis, Cal. Tech., 1978).

Called by: PGRIN

Calls: None

Input: DEL - epicentral distance in degrees

Output: GSPRD - the geometric attenuation amplitude loss factor

Subroutine RRFRD (RF)

The routine reads a file name, opens the disk file, reads a relative receiver function in the time domain, closes the file and manipulates the receiver function for convolution.

Called by: PGRIN

Calls:
OPENIN - opens diskfile for reading
CLOSE - closes diskfile
COOLB - Fast Fourier Transform routine
SPLIN3 - spline fit interpolator

Input: None

Reads: RRFID - name of diskfile containing desired receiver function

Output: RF - the desired relative receiver function in the frequency domain

Subroutine RDINST (FI)

This routine reads an instrument response file name, opens the file, reads the instrument response in the time domain, closes the file and prepares the instrument response for convolution.

Called by: SGRIN, PGRIN

Calls:
OPENIN - opens disk file for reading
CLOSE - closes disk file
COOLB - Fast Fourier Transform routine

Input: None

Reads: INSTID - name of diskfile containing desired instrument response

Output: FI - the desired filter for instrument response in the frequency domain

Subroutine HACK (KH, KS)

This is the calling routine for the Haskell matrix module. Computes Haskell matrix response for the six independent moment tensor components. This routine is called inside of nested loops on depth and station.

Called by:	MOTIVE	
Calls:	REMOD -	redefines crustal model to include artificial layer at current source depth
	WRATH -	Wave response of Thompson Haskell matrix. Does actual computation of the response functions
Input:	KH -	depth counter
	KS -	station number
	HMIN -	(from COMMON/DEPTH/) minimum depth
	DH -	(from COMMON/DEPTH/) depth increment
Output:	None	

Subroutine REMOD (H)

Redefines crustal model to include an artificial layer at current source depth.

Called by: HACK

Calls: None

Input:

H -	current source depth
NLAY -	(from COMMON/MOD/) number of layers
ALPHA -	" layer P-wave velocity
BETA -	" layer S-wave velocity
DENS -	" layer density
THICK -	" layer thickness

Output: (All in COMMON/MOD2/)

NL -	new number of layers = NLAY + 1
VP -	layer P-wave velocity
VS -	layer S-wave velocity
RHD -	layer density
TH -	layer thickness
LIS -	layer including source

Subroutine WRATH (KS)

Routine computes the source crustal P-wave response using a Thompson-Haskell matrix method (see, e.g., Haskell, J. Geophys. Res., 67, 4751, 1962). The layer matrices are manipulated to compute separate responses for each of the six independent moment tensor components.

Called by: HACK

Calls:
- HASK1 - computes layer matrices at a given frequency
- SMPHS - unwinds phase of response function
- INTRP - linear interpolator used to expand response defined at limited set of frequencies to full frequency range for convolution

Input:
- KS - station number
- /MOD2/ - see definitions in subroutine REMOD
- P - (from COMMON/STA/)ray parameter

Output: HMR (in COMMON/HAS/)
- contains the response functions for the six tensor components. This doubly dimensioned array could be visualized as including HMRXX, HMRYY, HMRZZ, HMRXY, HMRXZ and HMRYZ

Subroutine GRAFT (KS)

This is the calling routine for computation, manipulation and storage of final P-wave Green's function corrected for Haskell matrix response.

Called by:	MOTIVE	
Calls:	COOLB -	Fast Fourier Transform routine
	SMOOTH -	running average smoothing operator
	TSHFT -	apply a time shift to give proper alignment to Green's function
	UPNORM -	normalize to unit power
	PAW -	put current six components of Green's tensor response in Green's function vector.
Input:	KS -	station number
	PWC -	(in COMMON/PGREEN/) P wave correction factor
	HMR -	(in COMMON/HAS/) Six Haskell matrix responses, one for each moment tensor component
Output:	GV -	Green's function vector output via PACK

Subroutine TSHFT (X, DT, SEC)

Circular shifts X array by time 'SEC'.

Called by: GRAFT

Calls: None

Input:
X - array to be shifted
DT - sample interval
SEC - amount of shift. SEC greater than zero causes a right shift.

Output: X - shifted version

Subroutine MOTEST (MODE, MXLOOP, RESTES, MT)

Principal control subroutine for moment tensor inversion

Called by:	MOTIVE	
Calls:	ASETUP -	Sets up angle constants
	MATACM -	Accumulates design matrix from each data point matrix
	VECMAT -	Converts vector of n(n-1)/2 elements to n x n matrix
	MATINV -	Matrix inverter
	LSOLVE -	Matrix multiplier
	MSPLIT -	Converts best fit solution matrix into principal values and returns appropriate moment
	YPERTB -	Calculates new residuals
	RSTEST -	Tests residual and number of iterations against preset values
	DATACM -	Finds the new residual vector
	CNSTR -	Determines array which characterizes constraints for moment tensor matrix
	CONCOR -	Determines the matrix which relates the constrained and free solutions
	VARNC -	Calculates 95% confidence intervals
Input:	MODE -	Solution type 1. Free (no constraints) 2. Double couple 3. Double couple and isotropic 4. Isotropic
	MXLOOP -	Maximum number of iterations
	RESTES -	Residual test level
Output:	MT -	Best estimate of moment tensor

Subroutine ASETUP

Sets up angle constants (radians to degrees, etc.)

Called by: MOTEST

Calls: None

Input: None

Output: Passes arguments in labeled common -

COMMON/CONST/PI, R2DEG, DEG2R, SQRT2

PI:	π
R2DEG:	conversion factor for radians to degrees
DEG2R:	conversion factor for degrees to radians
SQRT2:	square root of 2

Subroutine MATACM (M, FR, NQ, YR, XM, YVEC)

Accumulates design matrix XM and data vector YVEC from each data point.

Called by: MOTEST

Calls:

1) PACK2 - Converts from natural elements of the moment tensor to double couple and isotropic form

2) WT2 - determines the weighting factors

INPUT:
M : number of data
FR: vector of partials for m^{th} datum
NQ: quality factor of m^{th} datum
YR: m^{th} datum

Output:
XM: $(FR)^T$ V (FR); F is the matrix of m^{th} partial, V is the variance matrix

YVEC: $(FR)^T$ V (YR)

Subroutine VECMAT (N, FVEC, FMAT)

Converts FVEC, a vector of n(n-1)/2 elements into an n x n matrix.

Called by:	MOTEST	
Calls:	None	
Input:	N	- dimension
	FVEC	- elements of $(FR)^T$ V (FR) (Matrix FMAT from MATACM)
Output:	FMAT	- matrix representation of FVEC

Subroutine MATINV (FMAT, NL)

Inverts FMAT using IBM SSP Gauss Jordan routines

Called by:	MOTEST	
Calls:	MINV -	Matrix inversion routine (SSP) using Gauss Jordan method
Input:	FMAT:	the NL x NL design matrix
	NL:	dimension of FMAT
Output:	FMAT:	inverted form of input design matrix

Subroutine LSOLVE (FMAT, YVEC, MSTART, NL)

Multiplies inverted design matrix FMAT and the residual vector YVEC.

Called by: MOTEST

Calls: None

Input: FMAT: NL x NL design matrix
YVEC: NL x 1 residual vector
NL: dimension

Output: MSTART: NL x 1 vector, best fit estimate of the elements of the moment tensor

Subroutine MSPLIT (MSTART, MOUNT, PRIN, ITYPE)

Converts MOTEST (best estimate of the elements of the moment tensor) into its principal values and returns to moment tensor conforming to the mode or type of solution specified in MOTEST.

Called by:	MOTEST		
Calls:	EIGEN	-	IBM SSP routine; rotates matrix to determine principal components
	PACK	-	Converts elements of MSTART to or from packed mode (double couple and isotropic).
	VC2ANG	-	Converts vector to coordinate angles
Input:	MSTART	-	Matrix containing the 6 elements of the best fit solution.
	ITYPE	-	mode of solution
Output:	PRIN	-	Eigenvectors, eigenvalues of $\underset{\sim}{M}$ [PRIN (1) = 1st eigenvaLue, PRIN (2) and PRIN (3) = θ, ϕ of eigenvector; similarly for PRIN (n), n = 4, 5, 6, 7, 8, 9; PRIN (10) = trace (isotropic part).]
	MOMNT	-	Appropriate typed moment tensor

Subroutine RSTEST (YVS, LOOP, NFLAG)

Tests residual and number of iterations against specified values.

Called by: MOTEST

Calls: None

Input:	YVS	-	residual
	LOOP	-	number of the iteration
	Labeled COMMON	-	COMMOD/INITVL/MXLOOP,
RESTES			
			(max. # loops, target residual value from MOTEST)
Output:	NFLAG	-	flag to indicate whether to exit from iteration scheme (NFLAG =
		-	2, exit)

Subroutine YPERTB (MOMNT, YVS, LOOP)

Calculates new residuals Y2 ($Y2 = Y_{obs} - F \cdot M$) to be stored in labeled common.

Called by: MOSTART

Calls: WT2 - determines the weighting factor V for the nth datum.

Input: MOMNT - current best solution for the moment tensor
LOOP - number of iterations

Output: YVS - residual
Y2 - residual matrix; contained in labeled common: COMMON/RDATA/

Subroutine RSTEST (YVS, LOOP, NFLAG)

Tests residual and number of iterations against specified values.

Called by:	MOTEST		
Calls:	None		
Input:	YVS	-	residual
	LOOP	-	number of the iteration
	Labeled COMMON	-	COMMOD/INITVL/MXLOOP,RESTES (max. # loops, target residual value from MOTEST)
Output:	NFLAG	-	flag to indicate whether to exit from iteration scheme (NFLAG =
		-	2, exit)

Subroutine DATACM (YVEC)

Finds the new residual vector [$F^T V$ (Y_{obs} - $F \cdot M$) = YVEC]

Called by: MOTEST

Calls: None

Input: (From labeled COMMON:
COMMON/COEFF/N, F (6,100), F2 (6,100)
COMMON/RDATA/Y1(400), Y2(400)
COMMON/QUAL/NQUA(400), V(400), V2(400)

V - variance vector
Y - observed data vector
F - partial derivative matrix

Output: YVEC - New residual vector

Subroutine CONSTR (ITYPE, NL, D, MOMNT)

Determines the NL x 6 matrix which characterizes the constraints for the moment tensor

Called by:	MOTEST	
Calls:	None	
Input:	MOMNT -	Current best estimate of the moment tensor
	ITYPE -	moment tensor type (= MODE from MOTEST)
Output:	NL -	# of lines in D
	D -	constraint matrix

Subroutine CONCOR (FMAT, D, NL, , B)

Determines the matrix that will relate the constrained and free solutions.

Called by:	MOTEST	
Calls:	MATINV -	matrix inversion routine
	MAPROD -	matrix multiplication routine
Input:	FMAT -	design matrix (the free solution)
	D -	constraint matrix
	NL -	# of lines in D
Output:	B -	NL x NL matrix relating free and constrained solutions.

Subroutine VARNC (FMAT, YVS, B, PRIN, DPRIN)

Calculates the 95% confidence intervals of the principal components.

Called by:	MOTEST	
Calls:	HEXT -	Rearranges inputs for VARNC
Input:	FMAT -	design matrix
	YVS -	Design matrix
	B -	matrix relating constrained and free solutions
	PRIN -	Eigenvalues and eigenvectors of the moment tensor
Output:	DPRIN -	95% confidence intervals of PRIN

Subroutine PACK2 (FIN, FOUT)

Converts from the natural elements of the moment tensor to double couple and isotropic form. This solely for the partials of F where A = FIN M = FOUT M'

A = amplitude
FIN = original factors
M = natural elements
FOUT = new factors
M' = packed elements

Called by: MATACM

Calls: None

Input: FIN - natural elements of $\underline{M}$

Output: FOUT - double couple and isotropic factors of $\underline{M}$

Subroutine WT2 (M, YR, LOOP)

Determines the weighting factor for the mth datum. Arguments are passed via COMMON.

Called by:	MATACM		
	YPERTB		
Calls:	None		
Input:	M	-	data number
	YR	-	Mth residual
Output:	V	-	variance function of quality factor
	V2	-	variance function of the residual and quality factor

(Output via COMMON/QUAL/)

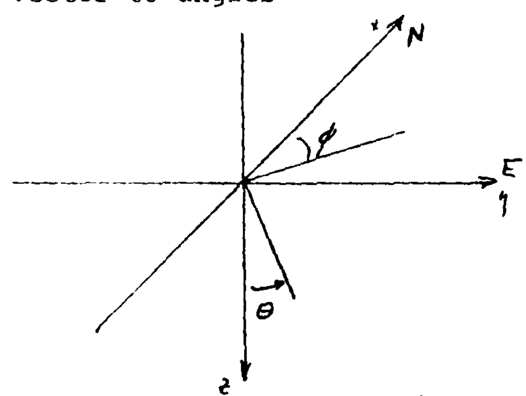
Subroutine PACK (MOMIN, MOMOUT, JMODE)

Converts elements of moment tensor to or from packed form.

Called by:	MSPLIT	
Calls:	None	
Input:	MOMIN -	input moment tensor
	JMODE -	flag indicating whether to convert MOMIN to (JMODE = 1) or from (JMODE = 2) packed form.
Output:	MOMOUT -	Packed or unpacked form of MOMIN

Subroutine VC2ANG (R, THETA, PHI)

Converts vector to angles



φ increases clockwise from N

θ increases counter-clockwise from vertical down

Called by:	MSPLIT
Calls:	None
Input:	R - input vector
Output:	THETA - θ PHI - φ

Subroutine HEXT (A, EIG, EIGV, SIGMA, C)

Arranges inputs for VARNC

Called by: VARNC

Calls: None

Input:

A - matrix to be analyzed
EIG, EIGV - principal components
V - covariance matrix of A
SIGMA - standard error of residuals

Subroutine MAPROD (A, B, I, J, K, C)

Matrix multiplier; calculates C = A B where A is a i x j matrix; B is a j x k matrix; C is a i x i matrix, i, j, and k $\leq$ 6

Called by:	CONCOR
Calls:	None
Input:	matrices A and B matrix dimensions I, J, K
Output:	matrix C

Subroutine DECIDE (H)

Major subroutine in decision and statistics module. Saves and ultimately prints moment tensor elements and total error for each depth. Computes data importance matrix for depth at which minimum error occurs. Prints variance matrix for that depth.

Called by	:	MOTIVE		
Calls	:	OUTPUT	-	Does plot output
Input	:	H	-	depth
		GV	-	(in COMMON/GREVEC/) Green's function vector
		DV	-	(in COMMON/DATVEC/) data vector
Output		GRSV	-	best fit Green's function array
		SVAR	-	variance matrix
		SAVSTF	-	Depth, moment tensor solution, amplitude of double couple component and total error for each depth.

Subroutine OUTPUT (X, Y, PLTID)

Plots data (X) and best fit synthetic (Y). Uses system plotting routines.

Called from	:	DECIDE		
Calls	:	system dependent plot routines		
Input	:	X	-	data seismogram
		Y	-	synthetic seismogram
		PLTID	-	plot indentifier
Output	:	graphic display of results		

List of COMMON blocks.

Detailed explanation of variable names are given on the following pages. The arrays must be dimensioned to be equal to or larger than minimum sizes determined by:

NS	:	number of stations. Counts surface waves and body waves as separate stations.
NSS	:	number of stations contributing surface wave data
NSP	:	number of stations contributing body wave data
NH	:	number of depths
NC	:	number of moment tensor components (always = 6)
NT	:	number of time samples (NPS or NPP)
NF	:	number of frequency samples (always 512 when stored)
NL	:	number of layers in crustal model

If no dimension specifications are provided, then variable is not an array.

COMMON/FLAGS/NSTAS, DTS, NPS, TSMS, NSTAP, DTP, NPP, TSMP

NSTAS, NSTAP	-	numbers of stations with input data for surface waves and P waves, respectively
TSMS, TSMP	-	time widths for running average smoothing operators
NPS, NPP	-	desired numbers of points in in input data and computed Green's functions
DTS, DTP	-	sample intervals

Required by:

MOTIVE

FLAP

SENSE

PENSE

PODIN

PGRIN

HACK

WRATH

GRAFT

MOTEST

DECIDE

COMMON/STA/STID (NS), DEL (NS), AZ (NS), QEFF (NS), TSTAR (NS), TAU2 (S), WT (NS), FNORM (NS), P (NS)

STID	-	four column station identifier
DEL	-	epicentral distance in degrees
AZ	-	Azimuth in degrees
QEFF	-	effective Q
TSTAR	-	travel time/effective Q
TAU2	-	absorption band parameter
WT	-	estimated station variance (quality)
FNORM	-	factor required to normalize seismogram to unit power
P	-	ray parameter

Required by:

SENSE

PENSE

PODIN

PGRIN

HACK

WRATH

DECIDE

COMMON/DATVEC/ISTA, ICOUNT, DV (NSS * NPS + NSP * NPP)

ISTA	-	station counter giving number of stations with data in the data vector
ICOUNT	-	point counter
DV	-	data vector of length ICOUNT into which the data from ISTA stations have been packed

Required by: PACK

MOTEST

COMMON/GREVEC/ISTA, JCOUNT, GV(NSS * NPS + NSP * NPP)

JUSTA	-	station counter giving number of stations with data in the Green's function vector
JCOUNT	-	point counter
GV	-	Green's function vector of length JCOUNT into which the Green's functions for JSTA stations has been packed

Required by: PACK

MOTEST

COMMON/DEPTH/HMIN, DH, NH

HMIN	-	minimum source depth
DH	-	increment of source depth
NH	-	number of source depths to be tested

Required by: FLAP

MOTIVE

HACK

COMMON/INV/NITER, ITYPE

NITER	-	number of iterations to be executed by inversion module
ITYPE	-	specifies type of source to be sought in inversion

Required by: FLAP

MOTEST

COMMON/HAS/HMR(NF, NC)

HMR	-	six components of Haskell matrix response, corresponding to the six moment tensor components (XX, YY, ZZ, XY, XZ, YZ)

Required by: WRATH

GRAFT

COMMON/GREEN/PWGF (NF, NC, NSP), SWGF (NF, NC, NSS)

PWGF	-	P-wave Green's Function
SWGF	-	Surface wave Green's Function

Required by: SENSE

GRAFT

COMMON/PGREEN/PWC (NC, NSP)

PWC	-	P-wave path correction factor including all factors but the Haskell matrix response

Required by: PGRIN

GRAFT

COMMON/MOD/NLAY, ALPHA (NL), BETA (NL), DENS (NL), THICK (NL)

NLAY	-	number of layers in crustal model
ALPHA	-	layer P-wave velocity
BETA	-	layer S-wave velocity
DENS	-	layer density
THICK	-	layer thickness

Required by: MODIN

REMOD

COMMON/MOD2/NLAYI, VP (NL), VS (NL), RHO (NL), TH (NL), LIS

NLAYI	-	new number of layers
VP	-	layer P-wave velocity
US	-	layer S-wave velocity
RHO	-	layer density
TH	-	layer thickness
LIS	-	layer including source

Required by: REMOD

WRATH

COMMON/PASS/DEPTH, TENS (6), AIS, ADC, PDC (3), VAR (36), ER

DEPTH - Depth
TENS - Moment tensor elements
AIS - Ampitude of isotropic component
ADC - Amplitude of double couple
component
DCD - Double couple orientation
VAR - Variance matrix
ER - Total error

Required by: MOTEST

DECIDE

COMMON/SGR/GRSV (512, 50, 6), SVAR (6,6), SAVSTF (13,30)

GRSV - Greens function array of best fit solution
SVAR - Variance matrix
SAVSTF - Depth, moment tensor solution, amplitude of isotropic component, amplitude of double couple component, double couple orientation and total error for each depth

Required by: DECIDE